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Techniques for processing metal matrix composite; A survey

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Abstract

In this paper the recent progress in the art of processing of metal matrix composite is reviewed. The discussion is based on manufacturing technologies involved, current and future products for advanced metal matrix and comparison of metal matrix composite techniques. The factors affecting the processing of metal matrix composite is subsequently discussed with wettability.

The future of advanced materials is related to systems solution, economical manufacturing processing, diverse markets and new technologies, the materials will provide the opportunity for growth to a new and healthier balance of metal matrix composites.

Keywords; metals,processes,composites

1. Introduction

Metal matrix composites, at present generating a wide interest in research fraternity, It is widely used as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

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2. Metal Matrix Composites

Metal matrix composites [10] have many advantages over monolithic metals including a higher specific modulus, higher specific strength, better properties at elevated temperatures, lower coefficients of thermal expansion and better wear resistance. Because of these attributes metal matrix composites (MMCs) are under consideration for a wide range of applications. The techniques used for fabrication of (MMCs) are as follows.

2.1 Liquid state fabrication of Metal Matrix Composites

Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding(wetting) between the dispersed phase and the liquid matrix should be obtained.

The methods of liquid state fabrication of Metal Matrix Composites:

- *Stir Casting*
- *Infiltration (or) pressure less melt Infiltration*
- *Disintegrated melt deposition*
- *Pressure Infiltration*

Stir Casting

Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. ZC63 Mg alloy-fly ash microballoon composites [1] were processed by melt stir technique. The melting was carried out using a resistance heating furnace. Crucible with a capacity to hold 2 kg of Mg was used for melting Mg and subsequent processing of composites. The desired volume fraction of fly ash microballoons with 100 μm average sizes and density of 0.6 g/cm3 was added manually into the vortex formed by stirring on the surface of melt. The result revealed that the addition of fly ash microballoon significantly reduces the density of the composites. As the volume fraction of microballoons increases, the density of the composites decreases. The microstructure of the composites demonstrates even distribution of the microballoon in the Mg alloy matrix and there is no sign of fly ash cluster or residual porosity. The fly ash microballoons, eutectic phase and other intermetallic compounds mix and segregate at the magnesium cell boundaries. The eutectic and other intermetallic compounds phases are able to heterogeneously nucleate on the fly ash microballoons,The fly ash reacts with the ZC63 Mg alloy to form reaction product at fly ash/matrix interface. The main interfacial phase between the fly ash and ZC63 Mg alloy is MgO. The composites containing microballoons up to 20 vol% significantly reveal higher energy absorption in comparison to the solid ZC63 matrix alloy or the composite containing 25 vol% microballoons

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Infiltration (or) Pressure less melts Infiltration

Infiltration is a liquid state method of composite materials fabrication, in which a preformed dispersed phase (ceramic particles, fibers, woven) is soaked in a molten matrix metal, which fills the space between the dispersed phase inclusions Ti_2AlC preforms (_50 vol.% porous) [2] were made by uniaxial coldpressing Ti_2AlC powders at 45 MPa. To carry out the infiltration process, pure Mg chunks were placed on top of the preforms that, in turn, were placed in Al_2O3 crucibles covered with Al_2O3 lids and placed in a graphite-heated hot press, HP under a vacuum of 10^{-2} torr, and held at 750 °C for 1 h, after which the furnace was turned off and the samples furnace cooled The result revealed that the density, measured by Archimedes's principle, was 2.87 ± 0.05 Mg/m^3, which was 98.5% of theoretical. The Ti_2AlC grain size was 20 ± 10 μm. The fractured surface however, showed the presence of sub-micron Mg single crystals . Interestingly, similar, but much larger, single crystals were formed on the surfaces of the Al_2O3 lids of the crucibles used to keep the Mg from evaporating. It follows that they most probably were formed by an evaporation/condensation process.

Disintegrated Melt Deposition

Magnesium based composites [3] containing 2.5wt.% of nano-sized Al_2O3 (50nm) particulates reinforcement were synthesized using an innovative disintegrated melt deposition technique and blend–press–sinter powder metallurgy technique followed by hot extrusion. DMD technique for composite fabrication involved melting and superheating the magnesium turnings with reinforcement particulates to 750°C under inert Ar gas atmosphere in a graphite crucible. Superheated slurry was stirred at 460rpm for 2.5min using a zirtex coated twin blade (pitch 45°_) stirrer to facilitate the incorporation and uniform distribution of reinforcement particulates in the metallic melt. The melt was then released through an orifice at the base of the crucible and disintegrated by two jets of argon gas, orientated normal to the melt stream, and subsequently deposited on to a metallic substrate. The result revealed that Micro structural characterization shows that a more uniform distribution of nano-Al_2O3 reinforcement in magnesium matrix and finer matrix grain size can be obtained using the DMD processing methodology when compared to PM processing methodology Results of coefficient of thermal expansion measurement indicate that dimensional stability of nano-Al_2O3 particulates reinforced magnesium can be significantly improved using DMD processing route when compared to PM processing route. The results of mechanical characterization revealed that both DMD and PM processing techniques lead to significant improvement in hardness, elastic modulus, 0.2% YS, UTS, ductility and work of fracture of magnesium matrix when nano-Al2O3 particulates are used as reinforcement Fractography revealed that fracture behaviour of magnesium matrix changes from brittle to ductile as a result of the presence of nano-Al_2O3 particulates in both of the materials

Pressure Infiltration

It is classified in to

- *Gas Pressure Infiltration*
- *Squeeze Casting Infiltration*
- *Pressure Die Infiltration*

Mg–xLi (x = 4, 8, 12) matrix composites [4] reinforced with short 8-alumina (Al_2O3) fibres were manufactured by the pressure infiltration process. A series of Mg–Li based composites were prepared by the gas pressure infiltration into a fibrous perform and powder metallurgy. Matrix alloys of composites exhibit (a) hcp (b), bcc (c) and mixture (a + b) structures. Compression tests were carried out in the temperature range from room temperature up to 300 °C. The results show that the mechanical properties and the deformation behaviour of composites are strongly influenced with temperature. The yield strength and maximum stress decreases rapidly with increasing temperature. The strain hardening rate decreases with increasing temperature. At higher temperatures, the true stress–true strain curves are flat – the strain hardening rate is close to zero. Cross slip of dislocations may be recovery mechanism leading to softening. For the composites with hcp matrix alloy in which cross slip is limited, there is a high strain hardening throughout the whole temperature interval studied. For bcc matrix alloys, in which the cross slip is easy, a two stage strain behaviour was observed in which there is a sudden lowering of the strain hardening capacity, the transition being attributed to the onset of cross slip. The load transfer and enhanced dislocation density were estimated as the most important strengthening mechanisms. Residual thermal stresses play also a significant role. Cross slip and subsequent annihilation of dislocations very probably cause softening. Local climb of dislocations in the vicinity of fibres supported by interface diffusion may also contribute to softening. The Hall– Petch effect has been found as the main strengthening mechanism in the Mg–8Li (p) composite, prepared by the powder metallurgy.

2.2Solid state fabrication of Metal Matrix Composites

Solid state fabrication of Metal Matrix Composites is the process, in which Metal Matrix Composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure.

There are two principal groups of solid state fabrication of Metal Matrix Composites:

- *Diffusion bonding*
- *Powder metallurgy*

Diffusion Bonding

Diffusion Bonding is a solid state fabrication method, in which a matrix in form of foils and a dispersed phase in form of long fibers are stacked in a particular order and then pressed at elevated temperature. The finished laminate composite material has a multilayer structure. Diffusion Bonding is used for fabrication of simple shape parts (plates, tubes). Diffusion bonding [5] was carried out using Cu interlayer at 540°Cand without interlayer at 540, 560 and 580 °C for different durations of 90, 120 and 150 min, under a vacuum of 30 Pa at constant pressure of 6MPa in a vacuum furnace (Kovaco KHP-200). Cross-sections of the bonded joints were prepared for metallographic analysis by standard polishing techniques. The result revealed that the shear strength of diffusion bonded joints using Cu interlayer increased with increasing of bonding duration due to dissolving the prior diffusion layers resulting in elimination of $CuAl_2$ brittle layer. The presence of primary Mg_2Si particles at the MMC/interlayer interface had a detrimental effect on shear strength of joints. As the distance from bonding centreline increased, the micro hardness value firstly increased and had a peak value at the base material/ interlayer interface and gradually decreased by progressing from peak point into the base material. Bonding duration had significant effect on shear strength of samples bonded using Cu interlayer and no substantial effect in non-interlayer diffusion bonding. Less deformation could be achieved with the same shear strength using

Cu interlayer. Mechanical properties were improved using Cu interlayer in comparison to non-interlayer diffusion bonding at the same bonding conditions.

Powder metallurgy

Powder metallurgy is an art and and science of producing fine metal powders and then making objects from it. Monolithic magnesium [6] and magnesium nanocomposites (Mg/Y_2O3) containing 0.5 and 2.0 wt. % of yttria powder were synthesized using powder metallurgy technique. The synthesis process involved blending pure magnesium powder with nanosized Y_2O3 powder in a RETSCH PM-400 mechanical alloying machine at 200 rpm for 1 h. No balls or process control agent was used during blending step. The blended powder mixtures of Mg and Y_2O3 were then cold compacted at a pressure of 97 bar (50-tons) to form billets of 35-mm diameter and 40-mm height using a 100-ton press. The compacted billets were sintered using an innovative hybrid microwave sintering technique. The billets were heated for 13 min to a temperature near the melting point of magnesium in a 900 W, 2.45 GHz SHARP microwave oven. The synthesis of monolithic magnesium was carried out using similar steps without adding reinforcement particulates for comparison purpose. Sintered billets were subsequently hot extruded at a temperature of 350°C using an extrusion ratio of 25:1.The result revealed that Distribution of reinforcement was dependent on amount of Y_2O3 particulates. Porosity was minimal and nanopores were observed. The increasing presence of nanosize Y_2O3 particulates leads to an increase in 0.2%YS, UTS, ductility and work of fracture. Coefficient of thermal expansion showed Reverse trend indicating an increase in thermal stability

When sintering is combined with a deformation operation, the fabrication methods are called:

- Hot Pressing Fabrication of Metal Matrix Composites
- Hot Isostatic Pressing Fabrication of Metal Matrix Composites
- Hot Powder Extrusion Fabrication of Metal Matrix Composites

2.3In-situ fabrication of Metal Matrix Composites

In situ fabrication of Metal Matrix Composite is a process, in which dispersed (reinforcing) phase is formed in the matrix as a result of precipitation from the melt during its cooling and Solidification. Different types of Metal Matrix Composites may be prepared by in situ fabrication method [7] There are five stages in In-situ synthesis Stage 1, in which the starting materials, of pure Mg and Al in ingot form, and the Si_3N4 powders, are heated to 700 °C for 50 min under vacuum in a sealed container installed in an electrical resistance furnace. Stage 2, in which the melt is moved into an electrical resistance furnace under the protection of SF_6/CO_2 gas atmosphere, and is then stirred at 575°C for 15 min to assist uniform dispersion of Si_3N4. Stage 3, in which the composite melt is held at 850 °C for 30 min to ensure complete reaction between Si_3N4 and Al according to: 4[Al]in Mg alloy + Si_3 N4(s) = 4AlN(s) + 3[Si]in Mg alloy. Once Si_3 N4 is completely converted to AlN, the melts contains 3.2 at. %Al and 3.8 at. %Si and thus lies in the fully liquid area according to the 850°C isothermal section of the Mg–Al–Si ternary phase diagram Stage 4, in which the composite melt is cooled to 610°C and stirred for 15 min. Mg_2Si is formed according to 2[Mg] + [Si] in Mg alloy = Mg_2Si(s) when the concentration of Si reaches saturation in Mg–Al–Si melts. Stage 5, in which the composite melt is re-heated to 700 °C and then poured into steel mould preheated at 200 °C to get resultant composites.

2.4Fabrication of Metal Matrix Composites by co-deposition

Co-deposition is a process, in which matrix metal is deposited together with the dispersed phase by one of the deposition techniques.

The following co-deposition methods are used for manufacturing Metal Matrix Composites:

- *Electrolytic co-deposition*
- *Spray co-deposition*
- *Vapour co-deposition*

Mg (99.9% purity) reinforced with 0.3, 1.3, 1.6 and 2 wt% of carbon nanotubes (average diameter: 20 nm and length: less than 100 μm) were fabricated using the disintegrated melt deposition technique (DMD) [8] and Multi-walled carbon nanotubes produced by the chemical vapour deposition (CVD) method were used the result revealed that The ductility increases with higher concentrations of CNTs until a peak is reached at 1.3 wt%. There is no observable change in the microstructures of Mg-1.3CNT nanocomposite as compared to monolithic Mg when viewed under the field emission scanning electron microscope (FESEM). More dislocations are generated in the Mg-1.3CNT nanocomposite as compared to monolithic Mg

.3. Result and Discussion

3.1Factor affecting processing of metal matrix composites

A number of factors can affect the processing of a metal matrix composite. Wet ability [9] between the reinforcement and the matrix alloy is one of the critical factors in the liquid processing. When the wettability is low, the mechanical agitation force in stirring casting, the pressure in squeeze casting, and the catalyst in infiltration are indispensable to overcome the surface energy barrier so that the reinforcement phases can be distributed into the molten alloy and the liquid metal can penetrate the reinforcement bed to form a strong bond. Wet ability can also be improved by increasing the surface energy of the solid, decreasing the surface tension of the molten metal, and decreasing the particle-matrix interface energy

3.2 comparisons of metal matrix composite techniques [10]

Route	*cost*	*Application*	*comments*
Diffusion Bonding	High	Used to make sheets,blades,vane shafts, structural components	Handles foils or sheets of matrix and filaments of reinforcing element

Powder metallurgy	Medium	Mainly used to produce small objects (especially round), bolts, pistons, valves, high-strength and heat-resistant materials	Both matrix and reinforcementsused in powder form; best for Particulate reinforcement; since no melting is involved, no reaction zone develops, showing high strength composite
Liquid–metal infiltration	Low/medium	Used to produce structural shapes such as rods, tubes, beams with maximum properties in a uniaxial direction	Filaments of reinforcement used
Squeeze casting	Medium	Widely used in automotive industry for producing different components such as pistons, connecting rods, rocker arms, cylinder heads; suitable for making complex object	Generally applicable to any type of reinforcement and may be used for large scale manufacturing
Spray casting	Medium	Used to produce friction materials, electrical brushes and contacts, cutting and grinding tools	Particulate reinforcement used; full-density materials can be produced
Compo casting/rheocasting	Low	Widely used in automotive, aerospace, industrial equipment and sporting goods industries; used to manufacture bearing materials	Suitable for discontinuous fibres, especially particulate reinforcement

4. Conclusions

There are four recurring principles that will shape the future of advanced materials:
Integrated process solution, Manufacturing by economy, Implementing system solution and more economical process in the market, new technologies.

4.1 Integrated Processes solution

Development of composite systems must be approached as an integrated process. Decisions regarding designs, processes and materials must be made synergistically to ensure peak product performance.

4.2 Manufacturing by economy

For composite material systems to grow successfully in the next century manufacturing Process must be made more economical, productive and efficient Composite technology has now matured to the point where larger and more complex structures can be produced with predictable, reliable mechanical properties

4.3 Implementing system solution and more economical process in the market

To obtain the best return on technology investment, systems solutions and more economical processes must be applied to new and diverse markets.

4.4New technologies

The final key to success for advanced materials will involve taking experience from both military and commercial applications and seeking out new technologies that are appropriate to the future of the industry. The challenge is to identify and focus on the right problems and opportunities that will facilitate a successful shift from basic science to functioning technologies.

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